Reprinted from
CROP SCIENCE, Volume 13
July-August, 1973, p. 466-469

Plant Measurements as Indicators of Crop Water Deficit[1]

R. N. Clark and E. A. Hiler[2]

ABSTRACT

An irrigation experiment was conducted with southern peas [*Vigna sinensis* L. (Endl.) var. 'Burgundy'] utilizing lysimeters in which the soil water balance could be controlled. The purpose of the experiment was to compare certain plant measurements as indicators of crop water deficit. Plant measurements made on stressed and nonstressed plants throughout the growing season were leaf-water potential, leaf-air temperature differential, and leaf-diffusion resistance.

Leaf-water potentials were measured by the pressure chamber method on well-exposed leaves. Leaf temperatures were measured by infrared radiometry and a diffusion porometer was used to measure leaf-diffusion resistance. Tensiometers were used to determine the soil-water potential and to time the irrigations.

The plant response data taken throughout a day were sensitive to water deficits during the late vegetative stage; however, the measurements were less responsive when the leaves aged, indicated by plants in the pod development stage. The change was particularly evident in the leaf-water potential measurements. All three plant measurements did indicate water deficit to some degree. Leaf-diffusion resistance was the least responsive, and leaf-water potential was the most responsive. Results relating leaf-water potential to leaf-diffusion resistance and soil-water potential are also given.

Additional key words: **Leaf-water potential, Leaf temperature, Leaf-diffusion resistance, Southern peas, *Vigna sinensis* L. (Endl.).**

THROUGH the years, man has used irrigation as a method for overcoming water stress in plants. This method is effective in reducing stress; however, timing of water applications is critical. To date irrigation timing has been based on the status of soil water, not on plant water (David, 1969; Jensen, Robb, and Franzoy, 1970). The status of the water in the plant represents an integration of the atmospheric demand, soil-water potential, rooting density and distribution, as well as other plant characteristics (Kramer, 1969). Therefore, to obtain a true measure of plant water deficit, the measurement should be made on the plant and not in the soil or atmosphere.

Water flows through the plant as a liquid from the soil to the leaves where it vaporizes and is released through the stomates into the atmosphere (Cowan, 1965; Kozlowski, 1968). Kramer (1969), Newman (1969), and Gates (1968) have pointed out that transpiration rate is controlled by the water-potential gradient and the resistances in the plant. As a water deficit develops in the leaves and the leaf-water potential decreases, the stomatal resistance increases and then the leaf temperature increases as a result of repartitioning of incoming energy. The main purpose of this study was to compare certain plant measurements as indicators of water deficit in southern pea [*Vigna sinensis* L. (Endl.)] plants throughout their growth cycle. Measurements selected for study included leaf-water potential, leaf-diffusion resistance, and leaf-air temperature differential.

PROCEDURE

Southern peas [*Vigna sinensis* L. (Endl.) var. 'Burgundy'] were grown in a lysimeter installation. The peas were planted May 6 and harvested July 14, 1970. The installation consisted of 12 lysimeters which contained undisturbed cores of Travis fine sandy loam. This soil had a sandy loam topsoil to 45 cm and a compact red sandy clay subsoil of considerable depth. Each lysimeter was 1 m in diameter and 2 m deep.

Before placement in the test area, each lysimeter was instrumented with a porous ceramic filter system placed in the bottom. This filter system was designed so that water could be extracted from the bottom and suction could be maintained to simulate a dry soil below. The lysimeter arrangement allowed for four treatments with three replications of each treatment. The area outside the lysimeters was used as a buffer area to simulate a field condition.

The influence of rainfall was removed from the experiment by a movable shelter that automatically covered the lysimeter area when rainfall occurred. A detailed description of the lysimeter installation has been presented previously (Hiler, 1969).

Four irrigation treatments were selected to give both stressed and nonstressed conditions. Specifically the treatments were as follows:

1. Irrigate when tensionmeter readings in the root zone equal —40 centibars in the amount of 1.1 times the measured soil-water losses from treatment 1;
2. Irrigate when tensiometer readings in the root zone equal —70 centibars in the amount of 1.1 times the measured losses from treatment 2;
3. Irrigate when number 1 is irrigated in the amount of 0.7 times the measured losses from treatment 3; and
4. Irrigate when number 2 is irrigated in the amount of 0.7 times the measured losses from treatment 4.

These treatments are designed to give a well-watered, nonstressed treatment (treatment 1) and three different levels of stressed treatments. In order to give a detailed explanation of the responses of the plant measurements to water deficits, plant measurement data from only treatments 1 and 3 will be discussed. A detailed report of this study has been presented by Clark (1970).

Meteorological measurements were made in and above the crop canopy to characterize the atmospheric environment around the plants. Air temperature, dew point temperature, wind movement, and net radiation were used to determine potential evapotranspiration (evaporative demand) from the crop. Also, the air temperature at the top of the canopy was used in the determination of the leaf-air temperature differential. From these meteorological measurements, daily potential evapotranspiration values were calculated by the method suggested by Van Bavel (1966) and Van Bavel, Newman, and Higleman (1967) with the surface roughness, Z_0, equal to 2 cm.

Soil-water potential was measured in each lysimeter at 15 and 30 cm with tensiometers. Soil-water content was measured by the neutron method at 15-cm increment depths down to 105 cm. The water content of the surface layer (0 to 8 cm) was determined by gravimetric sampling.

Leaf-water potential was measured by the pressure chamber method (Scholander et al., 1965). This measurement was accomplished by placing a freshly cut leaf or leaf shoot into the chamber with the cut end protruding and applying external pressure. The pressure necessary to balance the internal stress of the leaf or shoot and return the liquid from the xylem to the cut surface was considered equal to the negative hydrostatic pressure which existed in the plant just before it was cut. The pressure chamber method provides an indication of the hydro-

[1] Contribution from The Texas Agricultural Experiment Station, College Station, Texas 77843. Approved as Technical Article TA9127 of the Texas Agricultural Experiment Station. Received March 29, 1973.

[2] Agricultural Engineer, USDA Southwestern Great Plains Research Center, Bushland, Texas, and Associate Professor, Department of Agricultural Engineering, Texas A&M University, College Station, Texas.

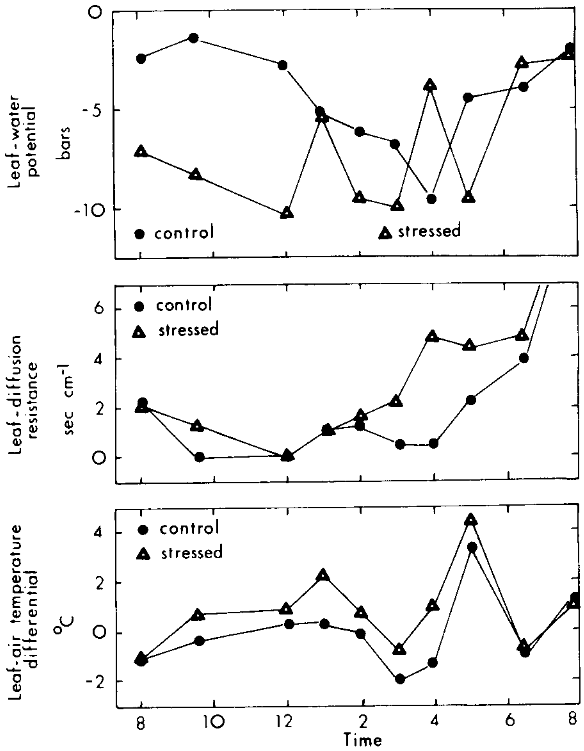

Fig. 1. Comparison of plant measurements made periodically on control and a stressed treatment for June 15 (late vegetative stage of growth).

static water potential and does not include the osmotic potential which is usually very small (Boyer, 1967). Boyer (1969) stated that measurements with the pressure chamber parallel those with the psychrometer sufficiently so that the pressure chamber technique is well adapted to experiments that compare one water potential to another and offers a higher accuracy than most other field methods.

Leaf-diffusion resistance was measured with a leaf-diffusion porometer similar to that developed by Van Bavel, Nakayama, and Ehler (1965). This meter consisted of a leaf cup that contained an electric hygrosensor for sensing humidity and a microampere meter for measuring the rate of change of humidity in the cup. The cup was clamped on the leaf and the time for a preselected change in current was measured. From the diffusivity of water vapor, the transit time, and the leaf temperature, the rate of water vapor diffusion from the leaves was calculated. When stomates were wide open, the rate of flow was high and the resistance was small. As the stomates closed and the rate decreased, the resistance increased.

Leaf temperatures were measured with a portable infrared radiometer. Noncontact surface temperature measurements can be made with this instrument. All measurements were made with the aid of a field definer and at a distance of 5 cm. The measurement area was 2 cm in diameter. The leaf-air temperature difference was determined by subtracting the air temperature at a height of 1 m above the crop from the leaf temperature. The air temperature was recorded at the same time as the leaf temperature was measured.

Measurements of leaf-water potential, leaf-diffusion resistance, and leaf temperature were made at approximately solar noon at College Station, Texas. In addition to these normal reading times, measurements were made on an hourly basis twice during the growing season, once in the late vegetative stage and once in the pod development stage. Leaves selected for measurement were the top, well-exposed leaves of similar size and age. A minimum of 12 leaves were selected each time to insure accuracy and reliability of readings.

RESULTS AND DISCUSSION

Dry matter yields were 4126, 3061, 2523, and 2391 kg/ha for treatments 1, 2, 3, and 4, respectively. Similarly, fresh pod yields were 1662, 1220, 1339, and 1232 kg/ha. Statistical analysis showed that treatment 1 was significantly different from treatments 2, 3, and 4 at the 5% level. Treatment 1 received 27.7 cm of irrigation water, almost twice as much as treatment 2 (15.7 cm) and three times as much as treatment 3 (10.3 cm). Treatment 4 received 8 cm of irrigation water. The data show that differential water stresses developed and that yields were reduced. The remainder of the results and discussion will be centered around a comparison of the control treatment (no. 1) and a stressed treatment (no. 3).

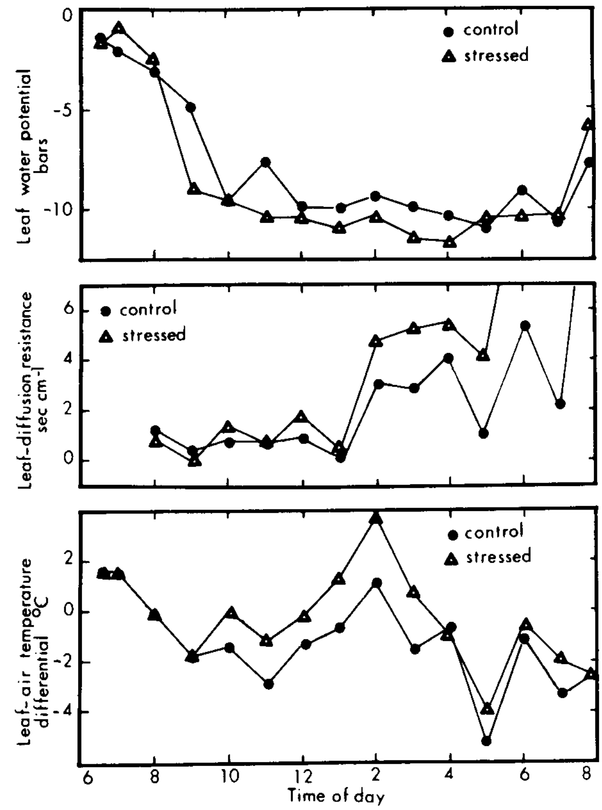

Fig. 2. Comparison of plant measurements made periodically on control and a stressed treatment for June 30 (reproductive stage of growth—pod development).

On June 15 and June 30, periodic daytime measurements were made of leaf-water potential, leaf-diffusion resistance, and leaf-air temperature differential. Figures 1 and 2 show a comparison of the control treatment (no. 1) and the stressed treatment (no. 3) for June 15 (late vegetative) and June 30 (pod development), respectively. For June 15 the leaf-water potential for the control remained above —3 bars until noon, gradually decreased to —9.6 bars at late afternoon, and then increased when the evaporative demand decreased (Fig. 1). The leaf-diffusion resistance and leaf-air temperature differential remained fairly constant until late afternoon when they increased. These values are similar to ones reported by Kanemasu and Tanner (1969) and Gates (1964) for well-watered plants. However, in the stressed treatment, water potential decreased to —7 bars before 8:00 a.m. and gradually decreased until it reached —10.3 bars at noon; then it fluctuated during the rest of the day between —3 and —10 bars. The leaf-diffusion re-

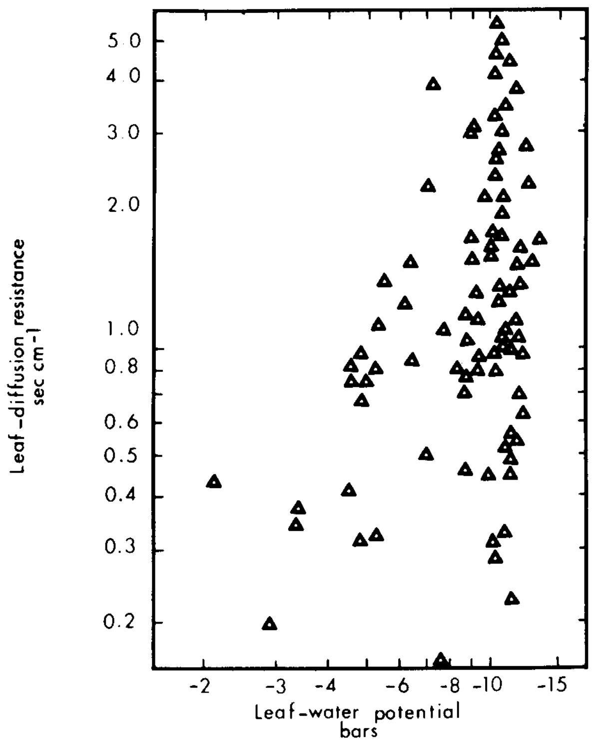

Fig. 3. The relation between leaf-water potential and leaf-diffusion resistance for southern peas.

sistance and leaf-air temperature differential for the stressed treatment were slightly higher than the control throughout most of the day except that leaf-diffusion resistance did increase rapidly between 3:00 and 4:00 P.M.

Results for June 30 during the pod development stage are shown in Fig. 2. The reactions of the various measurements were different from those on June 15 even though potential evapotranspiration and soil moisture were similar. Leaf-water potential for both the control and stressed treatments decreased rapidly during the morning and then remained rather constant until almost sundown. Although quite similar, most of the time the control values were inclined to be about 1 bar higher than the stressed values. Similar trends are shown for leaf-diffusion resistance and leaf-air temperature differential.

Figure 3 shows the relationship between leaf-water potential and leaf-diffusion resistance. Note that between —8 and —12 bars leaf-water potential, the leaf-diffusion resistance ranges from 0.25 to 5.5 sec/cm. These data correspond to those presented by Kanemasu and Tanner (1969) and show the closing of the stomates in a narrow range of leaf-water potentials. Because of this phenomenon, it is difficult to evaluate the water deficit imposed on a plant using leaf-diffusion resistance alone.

Figures 4 and 5 show three plant measurements, potential evapotranspiration, and soil-water potential

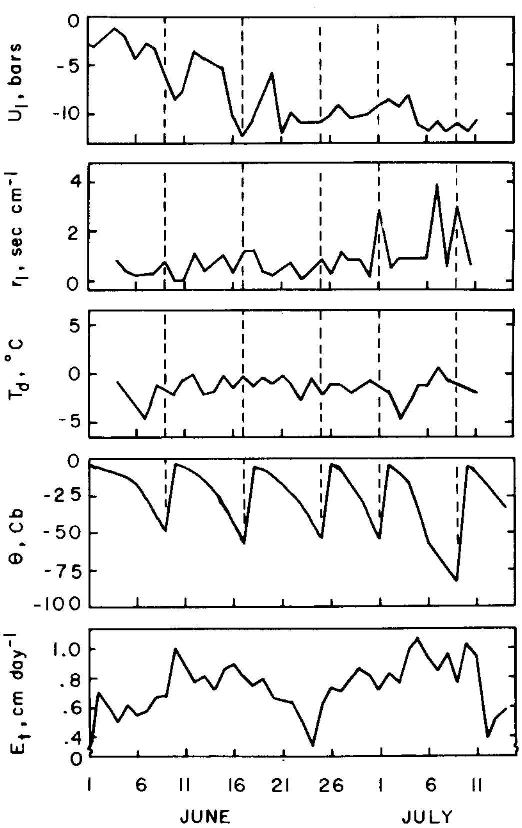

Fig. 4. Daily measurements for treatment 1 (control) of leaf-water potential, U_l; leaf-diffusion resistance, r_l; leaf-air temperature differential; T_d; soil-water potential, Θ; and potential evapotranspiration, E_t. Dashed lines indicate irrigations.

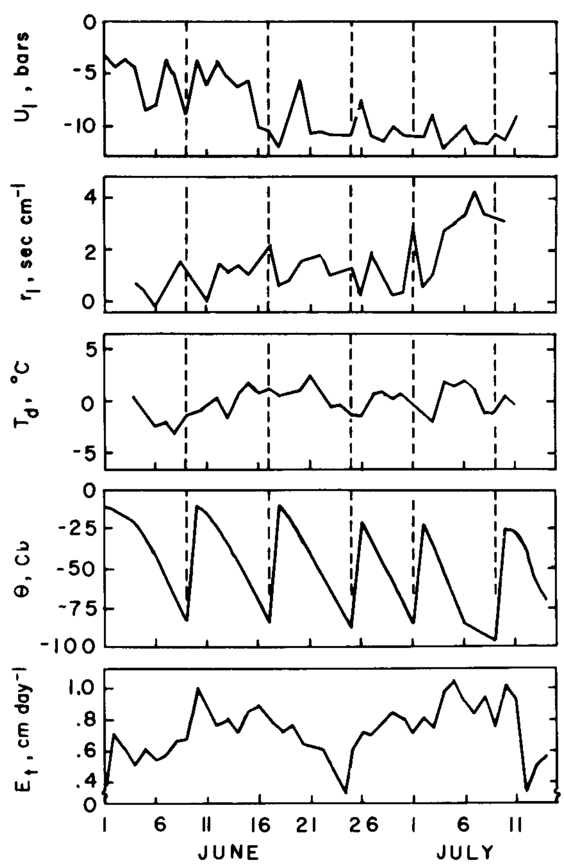

Fig. 5. Daily measurements for treatment 3 (stressed) of leaf-water potential, U_l; leaf-diffusion resistance, r_l; leaf-air temperature differential, T_d; soil-water potential, Θ; potential evapotranspiration, E_t. Dashed lines indicate irrigations.

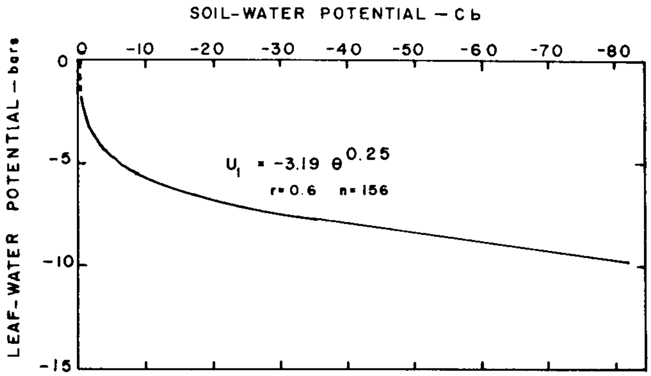

Fig. 6. The relation between leaf-water potential and soil-water potential for southern peas.

plotted against time for stressed and nonstressed conditions, respectively. Leaf-water potential became less responsive, in both treatments, to changes in water status after about June 25. This was approximately the time when most pods began to form in the reproductive stage and the time when vegetative growth ceased. However, all through the season the leaf-water potential did increase after each irrigation.

Leaf-diffusion resistance decreased after each irrigation. However, this measurement responded differently from leaf-water potential in that it became much more responsive in the latter stage of growth when leaf-water potential was least responsive. In each case the more water deficit a treatment was subjected to, the greater was the stomatal resistance for that treatment.

The data for leaf-air temperature differential show that in almost every case the leaves were cooler than the air above the canopy when the crop was well-watered. Once a water deficit occurred in the stressed treatment, the leaf-air temperature differential became positive and was usually 2 to 3 C warmer than the nonstressed treatment. It should be pointed out that leaf temperature is dependent on climate variables such as radiation and wind movement as well as the internal water status of the plant (Gates, 1968).

The plant measurements were not independent and they all gave an indication of the plant water status. When leaf-water potential decreased, leaf-diffusion resistance increased because of loss of turgor in the guard cells and then leaf-air temperature differential increased as would be expected because of the reduction in transpiration. Also, it was observed that leaf temperature and leaf-diffusion resistance were more dependent on the climatic conditions at the time of measurement than was leaf-water potential.

Because soil-water potential is often used as an indication of the plant-water deficit and can be used readily for timing irrigations with an automated irrigation system, the soil-water potential and leaf-water potential were compared (Fig. 6). Because leaf-water potential is dependent on the atmospheric environment as well as the soil-water potential, one would expect considerable scatter from different days with the same soil-water potential. This was found to be true; however, a reasonable correlation was established for southern peas. This correlation is valid only for this one location and soil type; nevertheless, the general shape of the correlation should be valid for most crops and soils. For values greater than —7 bars leaf-water potential and —20 centibars soil-water potential, the relation was linear.

The results of this study indicate that leaf-water potential as measured by the pressure chamber method was more responsive to changes in plant water status than either leaf-diffusion resistance or leaf-air temperature differential. Even though the leaf-water potential measurement was found to be better than the other two, it did indicate changes in water deficits better during the vegetative sage than the pod development stage. During this study, leaf-water potential seemed to be less dependent upon environmental factors and was a single measurement. By way of contrast, the leaf-air temperature differential required a measure of the leaf temperature and air temperature. Also, it was dependent upon the radiation intensity at the time of measurement [Wiegand and Namken (1966)]. Leaf-diffusion resistance was an awkward measurement to make, because two different determinations were necessary and its value varied considerably with the leaf temperature. The pressure chamber was found to be a quick and simple field method for indicating the plant-water potential of southern peas.

REFERENCES

Boyer, J. S. 1967. Leaf water potentials measured with a pressure chamber. Plant Physiol. 42:133-137.

————. 1969. Measurement of the water status of plants. Ann. Rev. Plant Physiol. 20:351-364.

Clark, R. N. 1970. Plant measurements as indicators of moisture stress in crops. Ph. D. Dissertation. Texas A&M University, (Mic. No. 71-17800). Univ. Microfilms. Ann Arbor, Mich.

Cowan, I. R. 1965. Transport of water in the soil-plant-atmosphere system. J. Appl. Ecol. 2:221-239.

David. W. P. 1969. Remote sensing of crop water deficits and its potential applications. Tech. Rep. RSC-06. Remote Sensing Center, Texas A&M University.

Gates, D. M. 1964. Leaf temperature and transpiration. Agron. J. 56:273-277.

————. 1968. Transpiration and leaf temperature. Ann. Rev. Plant Physiol. 19:211-238.

Hiler, E. A. 1969. Quantitative evaluation of crop drainage requirements. Trans. ASAE 12:499-505.

Jensen, M. E., D. C. Robb, and C. E. Franzoy. 1970. Scheduling irrigations using climate-crop-soil data. ASCE, J. Irri. Dr. Div. 96 (IR1):25-38.

Kanemasu, E. T., and C. B. Tanner. 1969. Stomatal diffusion resistance of snap beans. I. Influence of leaf-water potential. Plant Physiol. 44:1547-1552.

Kozlowski, T. T. (ed.) 1968. Water deficits and plant growth. Vol. I. Development, control, and measurement. Academic Press, New York.

Kramer, Paul J. 1969. Plant and soil water relationships. McGraw-Hill Book Co., New York.

Newman, E. I. 1969. Resistance to water flow in soil and plant. J. Appl. Ecol. 6:1-12.

Scholander, P. F., H. T. Hammel, E. D. Bradstreet. and E. A. Hemmingsen. 1965. Sap pressure in vascular plants. Science 148:339-346.

Van Bavel, C. H. M. 1966. Potential evaporation: The combination concept and its experimental verification. Water Resour. Res. 2:455-467.

————, F. S. Nakayama, and W. L. Ehler. 1965. Measuring transpiration resistance of leaves. Plant Physiol. 40:535-540.

————, J. E. Newman, and R. H. Higleman. 1967. Climate and estimated water use by an orange orchard. Agr. Met. 4:27-37.